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Research and Information Needs for Management of Oil Shale Development

Committee on Onshore Energy Minerals Management Research
Board on Mineral and Energy Resources
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

The Committee on Onshore Energy Minerals Management Research was organized by the National Research Council in response to a request from the U.S. Geological Survey's (USGS) Conservation Division of the U.S. Department of the Interior. In early 1982, the Minerals Management Service (MMS) was formed largely from the Conservation Division. In late 1982, the responsibility for onshore minerals management was transferred to the Bureau of Land Management (BLM). These agencies have or had major responsibilities for managing and coordinating mineral activities on public lands. These responsibilities include resource evaluation, approval of mineral development plans and regulatory duties during mineral operations, and postoperational plans for reclamation and monitoring. The primary objectives of the regulatory program are resource conservation, protecting life and property, and minimizing the risks of environmental and ecological degradation. The Committee, at the request of these agencies, is conducting a series of workshops to provide technical guidance on research needs in support of their regulatory responsibilities for onshore mineral activities involving oil shale, Alaskan oil and gas, uranium, and tar sands. Socioeconomic research has been excluded from the purview of this Committee.

This report provides an assessment of research needed to support the regulatory and managerial role of the BLM as well as others involved in the development of oil shale resources on public and Indian lands in the western United States. Such research costs incurred early could save enormous amounts later by obviating delays in projects already under way.

The material reviewed in preparation of this report was assembled and presented at the Workshop on Oil Shale Research Needs held June 22 and 23, 1982, in Denver, Colorado. The Workshop was organized by the Committee's Oil Shale Subcommittee to provide a forum for experts from academia, industry, and state and federal agencies, as well as environmental and user groups, to exchange their views on the wide

range of research issues central to oil shale development. (See Appendixes A and B for the workshop program and list of participants.) By the fall of 1983, the transcripts of these workshop presentations and general discussion are to be available for examination in the Archives of the National Academy of Sciences, and copies may be obtained through the Academy Archivist for appropriate reproduction, handling, and postage charges.

Although a number of lessee's approaches to the commercial production of shale oil have been attempted or tested, only one remains viable at this time--that of the Union Oil Company of California at Parachute, Colorado, which is scheduled to go into operation in mid-1983.

We hope that this information and analysis assists in clarifying oil shale research needs (priority needs are marked throughout this report with an asterisk) with subsequent benefit to the orderly development of this valuable public resource.

John S. Hutchins, Chairman
Oil Shale Subcommittee

John W. Rold, Chairman
Committee on Onshore Energy
Minerals Management Research

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AN OVERVIEW OF OIL SHALE RESEARCH AND DEVELOPMENT

The oil shales of the western United States long have been recognized as an exceptional potential hydrocarbon resource, mainly because the strata are thick and extensive and contain large quantities of organic material. Various sodium carbonates that occur with and within the beds of oil shale have many industrial applications. However, only the trona [$Na_3H(CO_3)_2 \cdot 2H_2O$] mines in Wyoming currently tap any of the mineral resources associated with the oil shales. Even though the oil shale resource is very large, and despite considerable progress through research and substantial investments in land and facilities since the early 1960s, commercial exploitation remains elusive. In 1982, as in the past, large oil shale development projects were recessed or abandoned for lack of economic promise.

Commercial development depends on complex politico-economic decisions related to world energy supply and on research that would make the oil shale resource economically feasible and environmentally acceptable. It is the research associated with these latter considerations that is the concern of this report. Given the present level of knowledge, what research should the scientific and engineering community pursue to foster and support environmentally acceptable oil shale development? And, which parts of such research are most important to the Bureau of Land Management (BLM) in the performance of its statutory roles?

These questions can be best answered after reviewing the general nature of the development problems and the areas of emphasis of past research. Most of the development problems are related to mining, extraction of the oil, and disposal of spent shale.

Kerogen, the organic material from which oil is recovered, occurs as microscopic particles locked in a dense matrix of finely crystalline dolomite [$CaMg(CO_3)_2$], the "shale" of oil shale. Kerogen is transformed to oil by heating (thermal cracking); significant recovery requires fracturing or grinding the impermeable rock matrix to provide access for the heat to the kerogen and the escape of the oil and gases produced. Moreover, the kerogen content

of oil shale is not uniform; it occurs in various concentrations in strata that change in thickness and number vertically and laterally through the several basins where oil shale is found. In general, the richest kerogen deposits lie toward the center of the former lake basins where the material was generated. These basins were later affected by tectonic forces and erosion, which exposed some of the rich deposits at the surface and caused others to be deeply buried. These variations in deposition, deformation, and erosion caused some areas to be more accessible and thus more attractive than others, such as parts of the Piceance Creek Basin in Colorado, where rich zones are accessible along cliff outcrops or at shallow depths.

Most attempts to develop oil shale have concentrated on areas of easiest access and on mining and surface retorting methods that are extrapolations of existing technology. Many of the mining procedures contemplate open-pit or room-and-pillar operations that are similar, but on a larger scale than most mines associated with other resources, such as limestone, copper, or salt. Crushing and grinding methods are similar to those used in the comminution of other resources, although considerable research has been done in developing innovations to cope with the elasticity and other rather special properties of these kerogen-bearing rocks. For many years, past research had been oriented principally toward improving efficiency of known techniques, scaling those techniques to much larger operations, or considering special problems of waste from these shales, all research of an incremental nature.

More recently, extensive research has been directed toward use of the more deeply buried or leaner portions of this resource. In modified in-situ methods, part of the shale is mined for surface retorting and part is heated or burned in the collapsed and rubblized subsurface mine area. Modified in-situ methods have undergone limited trials only in recent years, and the results have not been open to general evaluation. Even less research and limited development has been based on true in-situ methods, where the only access is by drilling. In true in-situ methods, fragmentation and oil formation (heating or solubilization) are accomplished entirely in the subsurface through manipulations from the surface. None of these methods appears practical or likely to be pursued in deeper deposits. As this report is brief, only some of these topics are covered in detail. However, the following are broad considerations:

- The oil shale resource, though enormous in terms of potential in-place barrels, is not easily used because of its rather low concentration of organics, physical and chemical properties, and location.

- Most successful U.S. attempts to recover shale oil have concentrated on open-pit or drift mining, coupled with surface retorting methods, or on modified in-situ methods. Most of the research has concentrated on adapting known technologies to this resource.
- So far, none of the methods developed has been extended to sustained commercial production.
- In-situ or modified in-situ methods have the appeal of using more deeply buried or a greater range of grade and thickness of oil shale. However, the technology appears to trail that of the mining/surface-retort method.

This situation offers some contradictions for federal management and regulation of oil shale development. The lack of a commercially demonstrated method for oil recovery from shale could result in less impetus for research. However, in contrast to historical development of other energy technologies, an opportunity is provided for careful assessment of the generic problems faced by government and industry in advance of major development. Therefore, the committee advocates the following important roles for the BLM:

- Provide coordination of the considerable but diverse oil shale data base through a central repository and information center for all nonproprietary oil shale related research. A complete library and, more important, a coordinated topical summary of existing research and research results, including those releasable by industry, are urgently needed.
- Provide coordination of nonproprietary research that brings together a committee made up of representatives from industry, state and federal agencies, and university groups. Such a committee should be charged with planning a comprehensive research program that includes engineering, environmental, biological, and other subjects of specific concern to the client. It should evaluate and recommend research on generic or cross-cutting projects for funding either directly by agencies and individual companies or by funds pooled from industry and governmental agencies. Wherever possible, integrated research using a systems approach with the intent of developing predictive models should be considered.
- Sponsor or support workshops and meetings where research information that is presented is summarized and published for public release.
- Encourage publication of research conducted from joint funding in easily available research journals, which should

reduce duplicate funding of costly research and will favor improved data acquisition.

These roles could be termed (1) information coordination, (2) research planning coordination, and (3) research information dissemination. The Committee believes that these roles will greatly aid the BLM in its regulatory and management responsibilities.

The remainder of this report describes in general terms the perceived research needs to facilitate liquid fuel and minerals production from oil shale in a commercially viable and ecologically sound manner. These research needs are divided into three categories: (1) information coordination; (2) generic research of broad scope, applicable to any oil shale related exploitation; and (3) specific research related to individual mining, recovery, or disposal methods. The Committee urges the BLM to play a major role in coordinating the research and information produced.

Because research and development on oil shale can only marginally affect economics, the urgent need for future assessment is not in evaluating data from models but the evaluation of data from actual commercial-scale operations. There will be little or no further progress in oil shale research and development until real and meaningful data on mining costs and the environmental impacts of these mines and retorts become available. The BLM is considered an appropriate depository for these data, which should begin to become available during the mid-1980s.

GEOLOGIC SETTING/RESOURCE BASE

The richest oil shale deposits in the United States are in the Green River Formation, deposited some 50 million years ago in a series of lakes that covered much of southwestern Wyoming, northeastern Utah, and northwestern Colorado. These lakes expanded and shrank in response to climatic fluctuations of their time. Subsequent tectonic movements formed structural basins that conform roughly with the ancient lake basins and have preserved remnants of their sediments in the Green River, Washakie, and Great Divide Basins of Wyoming, the Uinta Basin of Utah, and the Piceance Creek Basin of Colorado (Figure 1). Of all these basins, thicker and richer (higher kerogen content) oil shales were deposited and preserved in the Piceance Creek Basin, which comprises approximately three fourths of the known economically attractive resources of the Colorado, Utah, and Wyoming tri-state area. Because of the concurrence of early depositional centers and facies patterns, resources are considerably thicker and richer in the center of each former lake basin than along their shorelines. This is particularly marked in the Piceance Creek Basin (Figure 2), where less than 100 feet of oil shale occurs at the south escarpment, but shales thicken to over 1,800 feet in the basin center. Similarly, thick economically significant beds of evaporative minerals such as nahcolite ($NaHCO_3$), dawsonite [$NaAl(CO_3)(OH)_2$], trona [$Na_3H(CO_3)_2 \cdot 2H_2O$], and halite (NaCl), occur in the north central portion of present basins but are absent in the basin rims.

John R. Donnell, U.S. Geological Survey, retired (1982, personal communication), estimates 1.8 trillion barrels of oil resources in the tri-state area in beds thicker than 15 ft that are richer than 15 gal/ton. For this resource, some 600 billion barrels of oil might be ultimately recoverable using only current technology. To put these numbers in perspective, conventional Middle East oil reserves are estimated at 350 billion to 400 billion barrels, and United States crude oil reserves are estimated at less than 30 billion barrels (Energy Information Association, 1982).

FIGURE 1 Index maps of Piceance Creek Basin, Colorado (site locations and accessory mineral boundaries are approximate). SOURCE: Modified from Andrews et al. (1975); National Research Council (1979).

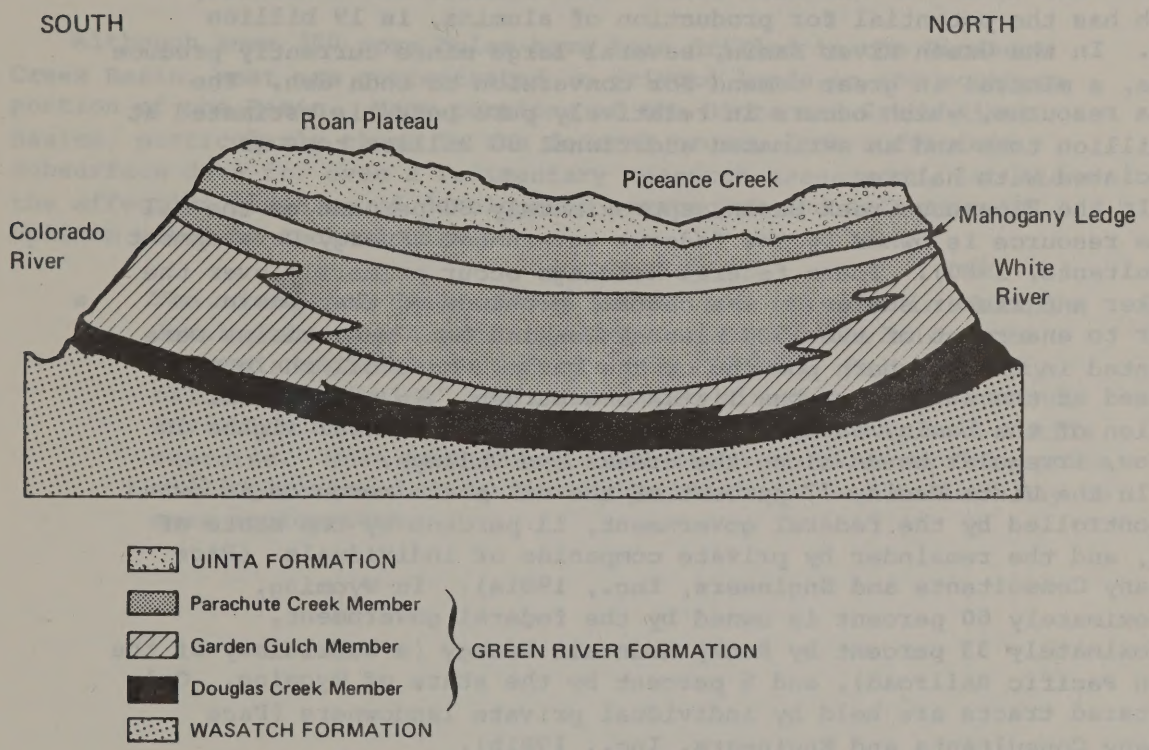

FIGURE 2 Diagrammatic section across the Piceance Creek area. SOURCE: Modified from U.S. Department of the Interior (1977); National Research Council (1979).

Donnell (1982, personal communication) estimates that substantial amounts of economically significant evaporative minerals (nahcolite, dawsonite, and trona) occur in association with oil shale. In the north central portion of the Piceance Creek Basin, he estimates 33 billion tons of nahcolite, which can be readily converted to sodium carbonate. U.S. production of sodium carbonate in 1981, all from natural deposits in the Green River Basin, Wyoming, and Searles Lake, California, exceeded 8 million tons. The estimate for dawsonite, which has the potential for production of alumina, is 19 billion tons. In the Green River Basin, several large mines currently produce trona, a mineral in great demand for conversion to soda ash. The trona resource, which occurs in relatively pure beds, is estimated at 67 billion tons and an estimated additional 30 billion tons is associated with halite.

In the Piceance Creek Basin, approximately 80 percent of the oil shale resource is owned by the federal government (Energy Development Consultants, 1980). These federal holdings occur primarily over the thicker and richer shales in the central portions of that basin. Prior to enactment of the 1920 Mineral Leasing Act, many claims were patented in the southern portion of the basin, where oil shale is exposed at the surface or has little overburden. In the central portion of the basin, early homesteaders acquired mineral rights in narrow, irregular bands along the creeks and valleys.

In the Uinta Basin, 77 percent of the oil shale resource is owned or controlled by the federal government, 11 percent by the state of Utah, and the remainder by private companies or individuals (Pace Company Consultants and Engineers, Inc., 1981a). In Wyoming, approximately 60 percent is owned by the federal government, approximately 33 percent by Rocky Mountain Energy (a subsidiary of the Union Pacific Railroad), and 5 percent by the state of Wyoming. Only scattered tracts are held by individual private landowners (Pace Company Consultants and Engineers, Inc., 1981b).

Additional information is needed to make a more accurate assessment of the resource magnitude, to determine its development potential, to plan development strategies, and to improve the government's understanding of the options in technology selection to be considered at various sites. These research needs include the following:

- Additional subsurface data are needed, not only for resource assessment, but also the physical, chemical, and mechanical characteristics of the rocks are needed for mine design, crusher design, waste stability, and technology selection.
- Additional chemical and mineralogical data of both oil shale and overburden are needed to assess any potential deleterious

impacts of resource development and beneficial economic by-products. Of specific concern is the distribution and potential interactive or chemical availability of trace metals occurring in shale, evaporite, or overburden.

- Additional assessment is needed of the expected resource recovery, employing the various technologies, and to find means to improve those recoveries and the economics of the processes.

Although some 300 core holes have been drilled in the Piceance Creek Basin, most are concentrated on private lands in the southern portion of the Basin. Many portions of the Uinta and Green River Basins, particularly those in the federal trust, lack sufficient subsurface data for even a rudimentary resource assessment, let alone the effective planning of development strategies and selection of optimum sites or technologies.

- The concept of "fair market value" and its role in resource development needs serious study and re-evaluation. True "recent comparable sales" are nonexistent. Painstakingly calculating "value" for undeveloped minerals in the ground, for which no commercial use has been proven, may be a futile exercise. More traditional definition of value as "the price willingly agreed to by knowledgeable buyer and seller" may be more appropriate.

3

MINING METHODS

Over the last 40 years, considerable mining of oil shale has occurred in supplying material for prototype retorts. In total, approximately 2 million tons have been removed to date from ten or more pilot sites in western Colorado and adjoining counties in Utah.

Oil shale is mined for above-ground retorting by surface (open-pit) or by underground room-and-pillar methods. The choice of the mining system is controlled by several factors, including depositional characteristics, such as richness and thickness of the oil shale deposit in relation to the amount of overburden that has to be removed. As the amount of overburden increases, the choice tends to favor underground mining methods because of the economic factors related to overburden removal. Surface mining creates the most surface environmental disturbance but has the distinct advantage of almost total resource recovery; so from the standpoint of effective resource utilization, it is preferred. As depth to the oil shale resource increases (see Geologic Setting) operators are influenced by increasing costs to convert from open-pit methods to another method, such as underground room-and-pillar mining, which requires leaving in place at least 30 percent of the minable zone for pillars to support the overburden and thus minimize (or eliminate) surface subsidence. Moreover, the generally considered 90-ft engineering maximum for underground mine heights sometimes hampers the mining of oil shale zones above or below the richest seams. Thus, in comparison with the near 100 percent recovery effectiveness of surface mining, underground mining effectiveness is reduced, not only by the underground pillars but also by mine height and other technical considerations. Where overburden increases substantially, as it does in the center of the Piceance Basin of Colorado, even larger pillars must be left unmined, which drops in-seam mining recovery well below 50 percent. At the same time, the operator incurs additional economic penalties, mostly for additional shaft costs; more underground mining, haulage, and

hoisting costs relatively little. Without efficient surface facilities, mining costs escalate prohibitively.

The alternative to open-pit and room-and-pillar mining is modified in-situ (MIS) retorting. With this technology, only the material required for access to the underground site and for creating a void for the rubble is removed. Then the oil shale bed is rubblized, and retorting takes place underground. With this method, resource recovery is limited, in part, by the barriers or pillars that must be left between in-situ retorts. Further, to date the yield of underground retorting is quite low, ranging from 20 percent to a recent reported 68 percent at Federal Lease Tract C_a. (See Figure 1.) The inefficiencies of low retort recovery, remaining barrier pillars, and limited seam height for retorting tend to limit the economic application of this mining method.

The difficulties for mining in the above systems--surface, underground, and MIS--derive not from the limitation of mining technology but from the depositional characteristics of the oil shale. Thus, for many years, some responsible sources have advocated large-scale surface mining of the oil shale resource with surface processing plants following the advance of the pit and stabilization of wastes with revegetation following the active pit. This approach is quite controversial because of large areas of surface disturbances. However, surface mining must be an option as it overcomes the economic disadvantages (less costly) of other techniques and has the advantage of almost total use (greatest efficiency) of the resource.

Research needs for mining relate primarily to underground mining methods, including modified in-situ, because known surface mining techniques are thought to be readily adaptable to oil shale. There are two categories of proposed research needs. These relate to new mining methods and equipment, and to mine health and safety, which would be more the responsibility of industry than of the federal government.

NEEDS

Methods and Equipment

- Optimize blasting materials and procedures.
- Develop movable primary crushers for in-mine use and integration with crushed-shale transport systems.
- Investigate applicability of continuous miners and related ground-support and transport systems.

- Optimize the design of large stable underground openings in oil shale.

Mine Health and Safety

*• Characterize the ignitibility and explosion suppression of oil shale dust, including the fire hazard of such dust in hot diesel-engine manifolds.
- Ventilate large openings (relative to possible gas release).
- Suppress fire in crushed oil shale stockpiles.

*Priority needs.

4

RETORT AND UPGRADE TECHNOLOGY

RETORTING

Retorting is a relatively simple concept: rock is crushed to enhance thermal transfer and is then heated to approximately 900°F (482°C) for a short period to vaporize the oil for removal. Because the oil shale to be retorted ranges in kerogen content, in associated minerals, and in the size of the crushed rock, over 20 retorting processes are in various stages of testing and evaluation. Thus, richness, purity, and particle-size variations in the crushed rock may require more than one type of retort on a single tract. No retort process has been tested at full-scale commercial production in the United States. (Open-pit mines in China, are reportedly mining and retorting 8 million to 10 million tons of shale per year (about 28,000 tons per day) and producing 320,000 tons of shale oil (Paul L. Russell, Denver, CO, personal communication, 1982).

The retort heating mechanism generically characterizes retorts into such groupings as those that convey heat using recycled hot gas, hot waste material, and external heat carriers, such as ceramic balls; others use more exotic means of heating, such as microwave fields. The major processes include BART; IITRI; STB; TOSCO II; Lurgi-Ruhrgas; Superior; Union A; Union B; Union SGR and SGR3; Paraho Direct; Paraho Indirect; Oxy MIS; RISE; Rio Blanco MIS; Equity TIS; Lofreco True In-Situ (TIS); Petrosix; Galoter; and Kiviter (underlined processes are patented or licensed by non-U.S. entities). None of these processes is now economically viable at current world oil prices.

Research, whether the responsibility of the federal government or more likely industry, should primarily address basic process innovations rather than refinements in existing methods. They should

- Seek to provide economies of scale by investigating larger projects and retort processes with process innovations to direct retorting selectively to kerogen content, rather than the inorganic content or nonthermal conversion of kerogen.

*• Improve beneficiation to remove inert materials before retorting.
- Develop ways to use excess carbon waste early or, alternatively, develop economic source of additional hydrogen.
- Encourage the development of methods for nonthermal conversion of kerogen, e.g., microwave, chemical, or biological.
- Depress the pour point of raw shale oil to improve its viscosity and stability for transportation to upgrading centers.

UPGRADING

Raw shale oil is a hydrogen-deficient hydrocarbon of high viscosity. Either removal of excess carbon as coke or addition of hydrogen (hydrogenation) lowers the viscosity and yields a transportable oil. Hydrogenation is preferred as it also removes sulfur and nitrogen and yields by-products such as elemental sulfur and ammonia, useful in the fertilizer market. The oil resulting from shale oil upgrading is a quality refinery feedstock.

Upgrading of shale oil is basically a refining process for which there is a wealth of technical experience. Thus, no research needs have been suggested for this area.

5

NEW TECHNOLOGIES IN THE DEVELOPMENT OF OIL SHALE RESOURCES

Oil shale resources are enormous, viewed in terms of oil that could be recovered from the thick strata of the western states. The real problem is finding ways of developing these organic materials economically. Developing technology has tended to concentrate on mining and retorting recovery, often using the modified in-situ (MIS) technique. Recently, however, difficulties with MIS has caused rethinking of this technology. To achieve large-scale production in the future, oil shale mines might need to be large excavations with several concentrated in a relatively small area. Additionally, the material mined must be retorted and disposed of. Such an operation has been likened to the problem of handling coal that is 80 percent ash at least three times. Problems such as these have caused industry to focus on the very highest grade deposits, like the rich Mahogany Zone of Colorado. Yet there are extensive lower-grade deposits in other zones of Colorado, as well as in Utah and Wyoming.

In-situ recovery techniques would circumvent many of these general problems of mining and surface retorting. The potential advantages of in-situ recovery have, of course, long been recognized. However, no true in-situ method has been developed or satisfactorily tested. Some frontier research pointed toward true in-situ approaches is needed.

In addition to the possibility of developing a totally new recovery technique, the broadest research needs are as follows:

- Greater understanding of fracturing and fragmentation properties and methods is needed. All potential recovery techniques require fracturing, crushing, or grinding because oil shale is dense and impermeable. Fragmentation techniques of many kinds should be tested, not just on the richest shale but also on the leaner interleaved strata. A comprehensive catalog of techniques and lithologically controlled response should be compiled.
- Better knowledge of the physics and chemistry of retorting is needed. Many organic and inorganic reactions occur as oil

shale is heated and complex physical changes take place. Surprisingly little is known about the full scope of these changes over a broad range of temperatures and pressures. Again, a basic research effort aimed at collecting a compendium of information is needed and might be used to suggest optimum in-situ or retorting conditions.

If we follow this general line of reasoning, research should be shifted to the broad "generic" type. For example, it serves little purpose to conduct much more research on revegetation or seepage from retorted spoil if surface retorting is uneconomic and unlikely to be done. Also, research on aquifer circulation may not be important if mines are driven in from the cliff outcrops or in unfractured areas of the basin but are of vital importance if enormous vertical modified in-situ chambers are contemplated. Research programs should be reviewed for their applicability to a wide range of possible future scenarios, or the most probable scenario first, developed before establishing research needs.

WATER QUANTITY

One of the major objections commonly raised against oil shale development is that it would impose an additional major element of water consumption in the already water-deficient Colorado River Basin. It is also argued that this consumption would impose additional problems of water-quality degradation in the already degraded Colorado River through diversion of high-quality water for industrial use and return to the Colorado system of low-quality water. Major issues relating to water quantity include determining consumptive use of water by various proposed oil shale extraction systems, the amount of water currently available, and the impacts of major oil shale mining and processing on water quantity and indirectly on water quality of the Colorado River system.

The sole local source of water in the oil shale region is precipitation, which ranges from 25 inches (660 mm) per year in the higher parts of the Piceance Creek Basin to as little as 3 inches (75 mm) per year in parts of the Green River Basin in Wyoming. Surface streams in the Piceance Creek Basin would support only a small part of the water demand of a major oil shale industry, which would be heavily dependent on throughflowing streams, such as the Colorado River.

The groundwater resources of the oil shale region are not well understood; only the Piceance Creek Basin has received detailed study. In general, aquifers throughout the region are recharged mainly by snowmelt in the higher parts of the basins and discharge at lower elevations along the Colorado River and its tributaries. In the Piceance Creek Basin, groundwater recharged around the perimeter of the structural basin, which has dissolved large amounts of soluble minerals in transit, discharges to the surface streams. This represents a significant contribution to the salinity load of the Colorado River.

WATER DEMAND

The estimated water demands of oil shale developments vary greatly depending on mode of extraction and processing methods. The largest water consumption per unit of product is associated with surface retorting, in which the largest element of water consumption is for disposal of retorted shale; other large water demands are for cooling and quenching of retorts and for cooling at accessory steam-electric generating stations. Conservative estimates suggest consumption of 3 to 4 volumes of water per volume of oil shale product. Modified in-situ systems consume considerably less water because of the lesser requirements for process cooling and disposal of retorted shale. True in-situ technology would have negligible water consumption. A 1-million barrels per day (BPD) industry using a mix of technologies could be expected to consume about 170,000 acre-feet per year, a ratio of 3.7 to 1.

Operations in the central part of the Piceance Creek Basin, which will require extensive dewatering to permit mining of the oil shale, may meet their own water demand from the required pumping. However, this water taken from storage is a withdrawal from the total water resources of the basin and will ultimately have to be replaced after dewatering operations cease. Operations in areas of sparse groundwater supplies will have to import water to their facility.

WATER AVAILABILITY

Surface-water availability in the Colorado Basin is governed by a complex set of state water laws, interstate compacts, international agreements, and court decrees, yet the legal availability of surface water is subject to much uncertainty. The U.S. Office of Technology Assessment (1980) estimate of 170,000 acre-feet consumption by a 1-million BPD industry represents about 1 percent of the virgin flow of the Colorado River at the Mexican border, or about 5 percent of the present water consumption in the Upper Colorado Basin. Estimates have been made that under present water allocation systems surface water availability will become a limiting factor at production levels ranging between 500,000 and 2,000,000 BPD (U. S. Office of Technology Assessment, 1980). All operations currently planned or under development appear to have secured sufficient water rights through purchase or contract. Presumably additional agricultural water rights could be purchased should surface rights prove inadequate for the future demands of an oil shale industry.

Estimates of groundwater in storage in the Piceance Creek Basin range from 2.5 million to 25 million acre-feet. The estimates date to

the U.S. Department of the Interior's (1977) Environmental Impact Statement on the prototype Oil Shale Leasing Program (U.S. Department of the Interior, 1973) and have not been narrowed subsequently because of insufficient information on the deep water-bearing zones of the Piceance Creek Basin. Some aquifers in the Uinta Basin appear capable of yielding large volumes of water, but no estimates are available on the amount of water in storage. Groundwater supplies are thought to be minimal in the Green River Basin.

POTENTIAL IMPACTS OF DEVELOPMENT

In general, consumption of water of high quality by the oil shale industry would tend further to degrade the salinity of the Colorado River, while consumption of saline waters, such as those currently discharged by Piceance Creek, would tend to improve the salinity of the Colorado. Diversion of irrigation supplies to zero-discharge industrial use would tend to improve the salinity balance of the Colorado. A unified water-management operation that maximizes industrial use of naturally saline waters, ensures against accidental discharges reaching the surface streams, and reduces input of degraded irrigation return waters offers the promise of a net improvement in the salinity of the Colorado River.

The most pressing research need in the area of water quantity is for refinement of estimates of available groundwater in storage in the Piceance Creek Basin. This will require the following:

- Deep drilling and aquifer testing of water-bearing zones in the Green River Formation below the Mahogany Zone in the Piceance Creek Basin are needed.
- These data should be used to develop and verify chemical transport models that simulate the flow of groundwater and dissolved minerals in the basin. Such modeling would also serve the needs in water-quality monitoring (see Water Quality).

7

ENVIRONMENTAL MONITORING

Environmental monitoring to establish baseline data for air and water quality, meteorology, wildlife, vegetation, soils, and other environmental parameters is essential so that effects can be assessed and adequate control technology provided to meet regulatory requirements and to minimize ecological impacts.

Rarely can environmental impacts be assessed (with statistical certainty) by simply increasing sampling efforts. Monitoring activities, to be effective, must consider the quantity and nature of the effluents, the likely behavior and distribution on release, and possible biological effects. Because oil shale is a new energy technology, the accuracy of forecasts of potential environmental effects will depend on a basic understanding of the regional environment and the behavior of emissions. Unique to oil shale development will be the unprecedented challenges associated with management of the huge quantities of solid waste and the potential for regional impacts in an area that has not experienced industrial development.

Potential impacts requiring monitoring can be classified as those pertaining to on-site impacts and to regional concerns that are the result of potential air and waterborne emissions. With open-pit mining and other surface operations, on-site losses arise largely from physical disturbances, which are both predictable and unavoidable. Mitigation of physical loss of habitat will require monitoring practices that can evaluate the success of reclamation activities (see Ecological Management).

Establishment of regional and cumulative effects from multiple dispersed oil shale operations will require the following:

*• A data archive for the region from which information on air and water quality and biota can be retrieved, evaluated, and used in assessment is urgently needed.

- Innovative statistical techniques are needed to limit sampling and establish methods for assessing potential cause-and-effect relationships.
- Biomonitors should be developed to serve as simple, inexpensive indicators of ecosystem stress, obviating the need for extensive ecological characterization.
- Control sites are needed to assure differentiation of natural fluctuations from impact related changes.

8

AIR QUALITY

Seasonal and diurnal wind systems are important in the analysis of air-quality impacts from oil shale production in the Green River Formation. The Piceance Creek Basin has a higher incidence of slope-valley (local) winds than the Green River and Uinta Basins because of its numerous canyons and valleys.

The current state of air quality over the Green River Formation is generally good. However, elevated background concentrations of particulate matter, non-methane hydrocarbons, and oxidants occur occasionally. These concentrations may result from natural and anthropogenic particulate releases, emissions from natural vegetation, long-range transport of man-caused pollutants, and stratospheric intrusion of ozone. The current data base, monitoring stations, and air-quality models are inadequate to determine the cause of these higher values and to evaluate effects on a regional basis.

Air-quality research needs include the following:

*• A review should be focused on collation, computer archiving, data filing, and interpreting (a) atmospheric structure data (temperature, humidity, and wind) for comparison with data from regional National Weather Service rawinsonde (balloon release) stations to determine applicability of the latter to the oil shale region (National Weather Service, 1971) and (b) upper-air data with time and space resolutions to determine whether available data are sufficient to drive regional air-quality models. This review would then provide the basis for subsequent research.

*• A cooperative program should be established to include the Bureau of Land Management (BLM), Forest Service (USFS), Environmental Protection Agency (EPA), Department of Energy (DOE), National Weather Service (NWS), National Science Foundation (NSF), and industry.

• A regional observation network in air-quality monitoring to provide information essential to mesoscale models and

assessment of accumulative regional impacts should be developed. This information would provide the background necessary to identify retorting parameters, environmental control measures, and stack characteristics (number, height, and flow volumes) that minimize overall impacts and provide optimum tradeoffs between local and regional impacts and impacts on different land classes.

9

WATER QUALITY

Considerable quantities of water will be required for oil shale development. Likewise, in areas where oil shale occurs, water is a particularly critical and valuable resource. Oil shale development may impact water quality during mining, processing, and waste disposal.

Although state and federal laws require, and industry plans for zero-water discharge operations, accidental and unforeseen releases have the potential for water-quality degradation. Impacts may arise from (1) disruption and cross-contamination of aquifers; (2) waste water from mining and dewatering operations; (3) waste waters from retorting, upgrading, and utility and sanitary wastes; (4) runoff from retorted shale piles and facility pads; (5) leachates from raw and processed shale piles and abandoned in-situ retorts; and (6) consumptive water use that reduces the dilution effect, therefore raising contaminant concentrations.

Water-quality research needs include the following:

*• Synthesize past and ongoing data-collection efforts.
*• Establish a regional monitoring system to allow the construction and effective use of regional surface and groundwater predictive models.
*• Establish key research models that integrate solute movement with water movement.

10

WASTE MANAGEMENT

The mining and processing of mineral resources have historically faced major waste-management problems and some of the experience (mining, refining, hazardous waste management) is directly applicable to oil shale. However, the scale, locations of oil shale development, and nature of retorting wastes provide some unique environmental challenges.

The major problem in waste disposal is the sheer magnitude of the wastes. One 50,000 BPD above-ground retorting operation processing 21 gal/ton shale oil will generate approximately 100,000 tons/day of processed shale.

Oil shale operations also generate other wastes with differing characteristics and handling properties such as mine water, retort waste water, raw shale dust or fines, spent catalysts, diatomaceous earth, deactivated carbon, and lime and alum flocculents. The large volumes of retorted shale and retort water (if disposed of to the retorted shale pile) will require special consideration.

The waste-management plan for an oil shale project must be designed to create a landform that will require minimal maintenance and at the same time function in long-term equilibrium with the natural environment, both on-site and off-site, particularly concerning surface stability (erosion rates, vegetative communities); mass stability; stream gradients; wildlife habitats; releases of chemical substances (runoff, leachates) to surface water and groundwaters; and hydrogeologic characteristics, both above and below ground.

Several federal agencies have supported laboratory and field studies to establish hydrologic and chemical balances for retorted shales. However, only limited laboratory investigations have dealt with possible codisposed materials, such as retort waters. Also, although a number of test plots and lysimeters have been constructed and considerable excellent reclamation-revegetation research has been conducted at various sites for some 20 years, a production operation is needed to validate much of the material developed. Much of the

work, particularly in terms of possible pollutant releases, has been focused on specific materials or problems with little attempt to examine stability, leachate, and reclamation problems in an integrated fashion. Only small-scale sites are likely until commercial operations are developed. The magnitude of this size constraint becomes apparent in light of the fact that all the material in the current test plots is highly heterogeneous and totals less than one day of production from a 50,000 BPD retort operation (Colorado Energy Research Institute, 1981).

Waste-disposal research needs include the following:

- *For the physical properties of processed shale wastes, shear strength parameters; compaction characteristics; effects of subsidence both on the surface and beneath waste facilities; effects of elevated temperatures on pile stability; and variation of physical properties with time, pile depth, leaching, and environmental exposure are needed.
- *For the chemical properties of processed shale wastes, information is needed on the nature and quantity of soluble trace elements, salts, and organic compounds (if retort water is codisposed) relative to background levels in soils and waters; the short- and long-term effects of waste pile configuration and different hydrologic regimes; and the variation of mineralogical and chemical properties with time and environmental exposure.
- *For the hydrogeologic properties of processed shale wastes, information is needed on the permeability and hydrologic conductivity of compacted wastes, the relation of permeability and conductivity to physical and chemical properties, and the variation of permeability with time and environmental exposure.
- For subsurface attenuation, there is a need to evaluate possible chemical attenuation by strata underlying waste sites as a possible means of reducing waste treatment and containment costs.
- For the geomorphic characteristics of processed shale wastes, we need to study erodibility, applicability of the Universal Soil Loss Equation, susceptibility to mass wasting (including landslides and mud flows), and overall geomorphic stability of processed shale landforms.
- For waste hydrologic transport models, we need to develop models based on fundamental relationships incorporating the foregoing physical, chemical, and hydrologic information to provide design, assessment, and predictive tools.

- For mitigation, we need innovative methodology to reduce waste volumes and potential hazards (e.g., concentration, beneficiation, chemical amendments, and accelerated weathering).

11

ECOLOGICAL MANAGEMENT

Regardless of the mining methods used (open-pit, room-and-pillar, in-situ) large areas of landscape will be modified. Consequently, rehabilitation procedures to re-establish stable soil-vegetation-animal systems are essential. Lands will be modified by roads, extraction plants, and towns. These will have a direct and indirect impact on air and water quality; wildlife, including waterfowl and fishes; as well as the impact of accelerated legal and illegal animal harvest. Integrated research is essential to mitigate these impacts effectively.

REVEGETATION

Revegetation is a critical component in the stabilization of surface-disturbed soils and spoil piles that will result from rubblized rocks and spent shales following retorting. Fundamental to a revegetation program is the development of a "soil" through the use of soil amendments. Central to this is the need to understand fully (1) water yield and quality from a spoil pile, (2) movement of salts and heavy metals within a spoil pile, (3) the concentration of boron and molybdenum in soil-plant systems and their potential toxic effect on livestock and wild herbivores, and (4) how to establish stable plant communities that will require minimal maintenance over time. This latter includes the need to understand the changes in soil organisms (microbes, fungi, and invertebrates) and plant species over time; a knowledge of plant succession leading to longer-term stable communities of plants and animals is essential.

The following research is needed to develop a more thorough understanding of the establishment and low-cost maintenance of stable soil-plant systems on processed shale piles and other surface-disturbed oil shale sites:

*• Conduct integrative studies on how soil-forming processes (time, soil and plant organisms, topography, and climate) are influenced by spoils derived from different retort processes and differing mineral composition.

• Develop new methods for physical and chemical analyses of raw and processed oil shale to better predict potential problems in the weathering process for soil development (release of heavy metals and salts) and the establishment of stable plant communities.

*• Systematically test different seed mixes, soil amendments, and fertilizers in relation to differing grades of oil shale, retort practices, and topographic-climatic regimes. This is essential because of the considerable geographic and topographic range of the oil shale lands.

• Long-term research is needed to determine the competitive interaction of plant species. This will enhance the development of predictive succession models for the establishment of stable plant communities that are of economic value for domestic and wild herbivores, timber, and watershed management.

WILDLIFE

Much of the Piceance Creek and Uinta Basins is inhabited by a diversity of terrestrial and aquatic wildlife species. The habitat requirements of some species (elk, deer, antelope, and rainbow trout) are well known, for others (squawfish and darters, for example) there is much less information. The direct and indirect impacts of large-scale oil shale plants on wildlife species is little known, yet certain predictions can be reasonably made now. Deer will adjust to urban centers and plant facilities more readily than cougar and elk. The synergistic effects of major energy developments (coal, oil, gas, and trona), recreation, and urbanization are little understood. Perhaps the most difficult activity to address or mitigate is the impact of larger human populations in these areas with the accompanying loss of critical habital and the increased legal and illegal harvest of mammals, waterfowl, and fishes.

There is a great need for the coordination and integration of existing wildlife data. To this end, the Northwest Colorado Wildlife Consortium was formed. A similar cooperative group should be formed for the Uinta Basin and the activities of both groups coordinated by an interagency group as discussed earlier in this report.

Wildlife research needs include the following:

- Develop long-term inventory records and habitat utilization maps for critical species and relate this information to the critical stages in the life history of the species. These data can help to mitigate future issues on loss of critical habitat and decreasing wildlife populations raised by sportsmen and naturalists. A holistic approach using population theory and modeling is essential.
- Behavioral studies on key wildlife species, not now well understood, can help to mitigate potential loss of critical habitat, especially for migratory species.

12

SUMMARY OF RESEARCH NEEDS

INFORMATION COORDINATION

It is recommended that the Bureau of Land Management (BLM) design a system to integrate public, private, and academic research related to oil shale (a compendium of oil shale developments in one place) with a mechanism for communicating and distributing research results on an annual basis to industry, government, and the public sector. A mechanism should be considered whereby lessees are required to make selected data, samples, and selected site access available to researchers. Developers of oil shale on private lands that represent 20 percent of the total western U.S. resource should be encouraged to participate in this effort to integrate the total data bank.

GENERIC RESEARCH

Geologic Setting/Resource Base

The BLM should support development of policy and technology for a comprehensive resource extraction program aimed at maximum resource recovery. This goal would be achieved by fostering research on the following broad topics:

- Regional geologic mapping, aimed at further documenting the distribution of oil shale and associated minerals on a regional scale is needed.
- Physical and chemical characteristics of oil shale and related rocks and minerals should be examined to explore their behavior over a wide range of conditions.
- Surface-water and groundwater hydrology should be studied in each of the major oil shale basins, and possible basinwide plans for underground dewatering in advance of mining and for controlling surface drainage should be made.

- Climatic, atmospheric, and hydrologic systems should be viewed on a regional scale and should include air- and water-quality studies.
- Total resource estimation is needed, using a variety of statistical or probability approaches and estimates of future world resource needs.

Recovery Methods

The BLM should encourage studies that lead to general advances in recovery methods, though this research might well be done or funded by industry. These could include design, performance, and haulage schemes toward innovative bulk mining operations; beneficiation approaches and techniques; in-situ or modified in-situ processes; and multimineral extraction procedures and problems. How to cope with methane and hydrogen sulfide that are commonly encountered in the center of the basins should be examined. Emphasis should be placed on economic evaluation and resource utilization of the various approaches, which is the crux of oil shale development.

Environmental Monitoring

Monitoring systems should be improved to increase the quality and reduce the cost of air- and water-quality studies. Methods are needed to quantify relationships between primary and secondary impacts and to develop a more systematic approach to environmental monitoring with a view to reducing redundant and unneeded data collection. With improved methods, it would be possible to have the following:

- A regional air-quality network, establishing present quality patterns and transport systems of longer-term pollutants;
- Surface-water and groundwater quality and quantity viewed on a regional scale, to predict the impact of mining or in-situ developments;
- Simplified methods of monitoring and estimating cause-effect relationships and impacts on biological systems on a regional scale.

SPECIFIC RESEARCH

Retorting and Upgrading Technology

Burned retorts at Federal Lease Tract C_a (Rio Blanco Oil Shale Company, Figure 1) provide a unique opportunity to gain information on water pollution potential, processing, retorting, rubblization, and the applicability of placing vertical modified in-situ retorts in wet zones. Also, on leachability of in-situ retorted oil shales, the BLM should encourage cooperation with other agencies and researchers to study retort abandonment and reclamation of terrestrial and aquatic systems where retort water seepage has occurred.

*Waste-Water Quality

Additional research is needed on effluents and groundwater movement, on resaturation of spent retorts, and on consolidated management of wastes that may enter surface water from spent shale. Hydrologic models need to be developed in sufficient detail to determine qualitative and quantitative impacts of local groundwater withdrawal and water introduction for specific sites and recovery processes. Deep exploratory drilling and aquifer testing is needed, especially in the Piceance Creek Basin, to provide a basis for firmer estimates of groundwater resources. Verification of hydrologic models is needed to enhance their value as predictive tools for the effects of development design and for efficient monitoring (see sections above on Geologic Setting/Resource Base and Environmental Monitoring).

*Waste Management

Investigations and monitoring are needed on the long-term physical and chemical changes, erosion effects, and hydrologic transport of leachates and particulates from processed shales as a function of retorting methods and conditions, methods of disposal (compaction, layering, slope), and location of disposal. Additional research needs include the feasibility of mine backfilling with processed shale, the economic and environmental considerations related to the regulatory control of fugitive dusts and gases, the relative environmental impact of various process alternatives, air and water emissions resulting from codisposal of process waters or treatment residuals with retorted shale, and the applicability of current water-treatment technology to aqueous effluents and leachates.

*Revegetation

The BLM should assemble and evaluate data now available to determine financial support and type of needed research on the long-term effects of overburden and waste-management practices on revegetation, including plant growth rates, vitality, salinity tolerance, bio-accumulation of trace elements, and plant succession to identify optimum methods for surface stabilization through establishment of stable plant communities. Such studies should determine the nutritive value of vegetation grown on various types of processed shale; identify the type and depth of materials needed for topsoiling processed shale; determine the ways and rate processed shale weathers to a natural functioning soil material; determine the long-term rate and direction of plant community succession on disturbed sites in different environments on different substrata; and ascertain how revegetation practices, plant species selection, and soil microbial activity influence the successional process. Such studies in conjunction with current plant breeding efforts help to develop improved seed and nursery stock of native plant materials for revegetation projects.

*Wildlife

Studies are needed to determine the relationship of regional and localized oil shale development to wildlife population dynamics, to develop better simplified techniques for establishing preoperational wildlife population dynamics and cause-effect relationships, to establish methodology for identifying critical wildlife habitat requirements, to select methods for restoring and enhancing critical habitats, and to develop information on tolerance and intolerance of wildlife species to human activity associated with oil shale development.

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APPENDIX A

WORKSHOP ON OIL SHALE RESEARCH NEEDS

Regency Hotel
Canterbury/York Rooms
Denver, CO
June 22-23, 1982

PROGRAM AGENDA

June 22

Morning Session - Moderator: Mr. John W. Rold

Welcome and Introductions	Mr. John W. Rold, Committee Chairman Mr. John S. Hutchins, Workshop Chairman
Managerial and Regulatory Responsibilities of the Minerals Management Service in Oversight of Oil Shale Operations	Mr. Roger A. Tucker
Managerial and Regulatory Context of Industrial Development of Oil Shale Resources	Mr. Douglas S. Moore
Assessing Oil Shale Resources	Mr. John R. Donnell

Afternoon Sesion - Moderator: Mr. John S. Hutchins

Mining and Production Methodologies in the Extraction of Oil Shale Resources	Mr. Robert B. Crookston
Retorting and Upgrading of Oil Shale	Dr. Thomas A. Sladek
Waste Management Practices in the Operation of Oil Shale Facilities	Mr. David C. Shelton
Summary Discussion of the Day's Activities	

Evening Session - Moderator: Mr. John W. Rold

U_a Oil Shale Operation and Special Research Needs for Managing the U_a Tract and Similar Oil Shale Activities	Mr. James W. Godlove
Technologies of Multi-Mineral Development and Production in Association with Oil Shale Operations	Mr. Ben Weichman

June 23, 1982

Morning Session - Moderator: Mr. John S. Hutchins

Revegetation of Oil Shale Sites	Dr. Edward F. Redente
Monitoring the Environmental Impacts of Oil Shale Development with a Specific Emphasis on Air Quality	Mr. Allen N. Verstuyft
Influence of Oil Shale Development on the Water Quality and Quantity	Dr. Willard R. Chappell Mr. Glen Miller

Afternoon Session - Moderator: Mr. John W. Rold

Influence of Oil Shale Development on Wildlife Resources	Mr. Perry D. Olson
Concerns of the Environmental Community in the Development of Oil Shale Resources	Mr. Kevin Markey (did not appear)
New Technologies in the Development of Oil Shale Resources	Mr. Arthur Hartstein
Summary Discussion of Workshop Activities	Messrs. Hutchins and Rold

APPENDIX B

PARTICIPANTS IN THE WORKSHOP ON OIL SHALE RESEARCH NEEDS

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